Sea

System of waves observed at a point which lies within the wind field producing the waves.

Sea (wind waves); Bf 10; North Sea platform Helder (photo by Jan van Grondelle)

Swell

System of waves observed at a point remote from the wind field which produced the waves, or observed when the wind field which generated the waves no longer exists.

Long swell of medium height (3 - 4 metres); fishing vessel nearly disappears behind a swell wave (photo Deutscher Wetterdienst)

Wave direction

The direction from which the waves are coming is most easily found by sighting along the wave crests and then turning 90° to face the advancing waves. The observer is than facing the direction from which the waves are coming.

Wave period

The period of the waves is the time between the passage of two successive wave crests past a fixed point. The average value of the wave period is reported, as obtained from the larger well-formed waves of the wave system being observed.

This is the only element which can actually be measured on board moving merchant ships. If a stopwatch is available, only one observer is necessary; otherwise, two observers and a watch with a second hand are required. The observer notes some small objects floating on the water at some distance from the ship: if nothing better is available, a distinctive patch of foam can usually be found which remains identifiable for the few minutes required for the observations. He starts his watch when the object appears at the crest of the wave. As the crest passes on, the object disappears into the trough, then reappears on the next crest, etc. The time at which the object appears to be at the top each crest is noted. The observations are continued for as long as possible; they will usually terminate when the object becomes too distant to identify, on account of the ship's motion. Obviously, the longest period of observation will be obtained by choosing an object initially on the bow as far off as it can be clearly seen.

Another method is to observe two or more distinct consecutive periods from an individual group while the watch is running continuously: with the passage of the last distinct crest of a group or the anticipated disappearance of the object, the watch is stopped, then restarted with the passage of the first distinct crest of a new group. The observer keeps count of the total number of periods until he reaches 15 or 20 at least. With observations of a period less than five seconds and low wind velocity, the above observation may not be easily made, but such waves are less interesting than those with longer periods.

Wave height

The average value of the wave height (vertical distance between trough and crest) is reported, as obtained from the larger well-formed waves of the wave system observed.

The following guide show roughly which height of WIND WAVES (SEA) may be expected in the OPEN sea, remote from land. In enclosed waters, or when near land with an offshore wind, wave heights will be smaller and the waves steeper. Furthermore, the lag effect between the wind getting up and the sea increasing should be borne in mind.

wind force [Beaufort]	probable height [metres]	probable max. height [metres]
0	0	0
1	0.1	0.1
2	0.2	0.3
3	0.6	1
4	1	1.5
5	2	2.5
6	3	4
7	4	5.5
8	5.5	7.5
9	7	10
10	9	12.5
11	11.5	16
12	14	-

Significant wave height

The average height of the 1/3 highest waves. I.e., if all wave heights measured from the record (samples computer saved) are arranged in descending order, the 1/3 part, containing the highest waves, should be taken and significant wave height is then computed as the average height of this part. Significant wave height roughly approximates to visually observed wave height.

The complex nature of wave motion at sea

The action of wind in producing waves is not precisely understood. The effect of the wind varies from the tiny ripples ruffled on a pond by the merest breath of air to the mighty rollers of the North Atlantic and Roaring Forties. All ocean waves, other than those caused by movements of the sea floor and tidal effects, owe their origin to the generating action of the wind. Wave motion, however, may persist even after the generating force has disappeared, being then slowly dissipated by frictional forces.

An observer of the motion of the sea surface at a particular place will, in general, notice a complicated wave form such as is shown in Figure 23, which may be regarded as the result of the superposition of a number of simple regular wave motions having different lengths and speeds. The ideal observer is an instrument known as a wave-recorder which registers automatically the up and down motion of the water surface and enables a record such as Figure 20 to be drawn. This record can be analysed or split up into its component simple waves. Most wave- recorders can only be effectively used from the shore, offshore installations or from stationary ships and hence it is not possible to measure sea disturbance in general by this method although it would be most desirable to do so.

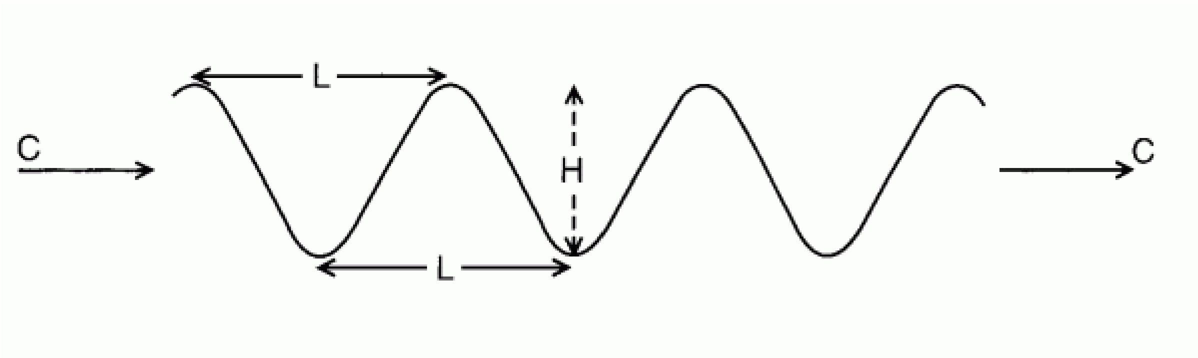

Figure 20. Characteristics of a simple wave.

The distinction between sea and swell

The system of waves raised by the local wind blowing at the time of observation is usually referred to as 'sea'. Those waves not raised by the local wind blowing at the time of observation, but due either to winds blowing at a distance or to winds that have ceased to blow, are known collectively as 'swell'. Usually, one component of the swell dominates the rest, but occasionally two component wave motions crossing at an angle may be observed. These are referred to as 'cross swells'. Sea and swell may both be present at the same time and the sea may be from a different direction and have different period and height to the swell, or both sea and swell may be from the same direction.

The characteristics of a simple wave

The following definitions are used in describing a simple wave:

1. (a) SPEED, C, usually expressed in knots, is the speed at which individual waves travel.
2. (b) LENGTH, L, expressed in metres, is the horizontal distance between successive crests or successive troughs.
3. (c) PERIOD, T, expressed in seconds, is the time interval required for the passage of successive crests (or successive troughs) past a given point.
4. (d) HEIGHT, H, expressed in metres, is the vertical distance between the top of a crest and the bottom of a trough.

The following relations are found to hold for a simple wave:

Speed = 3.1 x period
Length = 1.555 x (period)^2 metres.

(In application to actual sea waves, which are not simple, the constant 1.555 should be reduced by a factor ranging between about 1/2 and 1/3.)

By means of these formulae, measurements of one of the variables can be used to calculate the other two. The following table gives these relations numerically for different wave periods:

Period	Length	Speed
seconds	*Metres*	*Knots*
2	6.2	6.2
4	24.9	12.4
6	56.0	18.6
8	99.5	24.8
10	155.5	31.0
12	223.9	37.2
14	304.8	43.4
16	398.0	49.6
18	503.9	55.8
20	622.0	62.0

There is no inherent theoretical relation between the height and period of a simple wave. We can imagine the height to be varied at will, the period (and hence length and speed) remaining constant. In real wave motion, however, in which many simple waves are superposed there is a further consideration that enables us to see how the height is limited. If we call the quotient H/L the 'steepness' of the wave, it is found that the mean steepness does not increase beyond 7.6 per cent (1/13). If the mean steepness is less than this figure then the waves are capable of absorbing more energy from the wind, thus increasing their height relative to their length. When the limiting steepness is reached, surplus energy received from the wind is dissipated by the breaking of the waves at the crests (white horses). This limiting value of the steepness explains why the mean maximum height of the sea waves is roughly in proportion to their length; for example, wind-driven waves of length 120 m (period 9 seconds) would not be expected to have a mean maximum height greater than 9 m. If the wavelength were about 150 m (period 10 seconds) this limiting value of the mean maximum height would be increased to 12 m. On the other hand, long swells, perhaps 300-600 m in length, may have heights of less than half a metre.

When the height of the wave is small compared with its length, the wave profile can be adequately represented by a simple sine curve. As the height becomes relatively greater, however, it is seen that the crests become sharper and the troughs much more rounded, the precise profile being a curve known as a 'trochoid'. This is the curve that would be traced on a bulkhead by a marking point fixed to the spoke of a wheel, if we imagined the wheel to be rolled along under the deckhead.

In Figure 21 the large circle represents the wheel and P the marking point on a spoke, OP, the distance from the axle being called the tracing arm. The arrow shows the direction in which the circle rolls and in which the wave is supposed to be travelling. AB is the base, i.e. the straight line under which the circle is to roll, the length AB being equal to the half circumference of the wheel, AR.

Now as the circle rolls, when position 3 of the circle reaches position 3 of the base, the semicircle FPG will be in the position shown by the dotted semicircle; and the marking point P will coincide with the point D, having described part of a trochoid PD. When the circle has completed half a revolution, the marking point P will coincide with E, having described the trochoid curve PDE which is half a wavelength; the diameter POH represents the height of the wave. The nearer the marking point is to the axle of the wheel, the flatter will be the trochoid.

In an ideal wave each water particle revolves with uniform speed in a circular orbit, perpendicular to the wave ridge (the diameter of the orbital circles being the height of the wave) and completes a revolution in the same time as the wave takes to advance its own length. At a wave crest the motion of the particles is wholly horizontal, advancing in the same direction as the wave; at mid height on the front slope it is wholly upwards; in the trough it is again horizontal but in the opposite direction to the travel of the wave, and at mid height on the back slope it is wholly downwards. This motion may be seen by watching a floating object at the passage of a wave. The object describes a circle but is not carried bodily forward by the wave

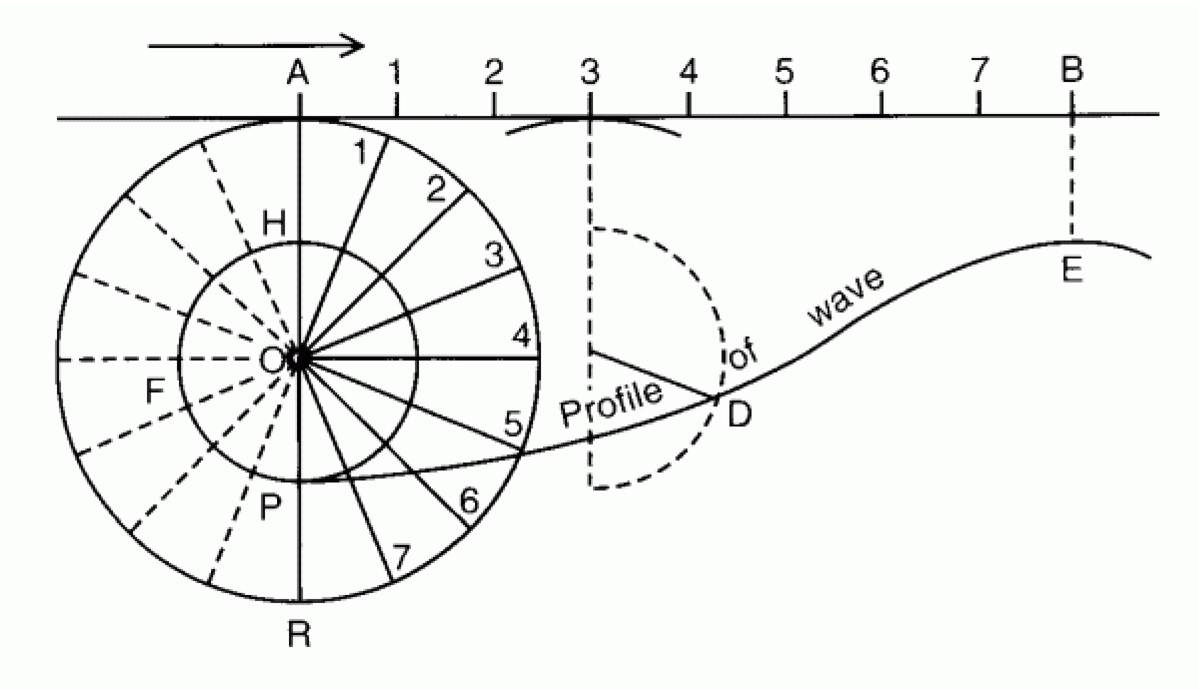

Figure 21. Representation of a trochoidal wave form.

The disturbance set up by wave motion must necessarily extend for some distance below the surface; but its magnitude decreases very rapidly in accordance with a definite law, the trochoids becoming flatter and flatter as the depth increases, and the water particles revolving in ever- decreasing circles. At a depth of one wavelength the disturbance is less than a five-hundredth part of what is at the surface, so that the water at that depth may be considered undisturbed. The motion associated with the largest ocean waves is inappreciable at even moderate depths, as is demonstrated by experience in submarines.

Wave groups

Experience shows that waves generally travel in groups with patches of dead water in between, the wave height being a maximum at the centre of each group. We have said earlier that any observed wave motion can be regarded as built up from a number of simple wave forms. Let us consider, for example, the superposition of two simple wave motions having the same height but slightly different periods. If the crests of the two wave motions are made to coincide at the initial point of observation the height of the resultant wave will be twice that of each component wave. To each side of this point, however, owing to the difference of period, the additive effect becomes less until a point is reached where the heights of the component waves, being of different sign, completely annul each other's effect. Beyond this point the heights again become additive until the troughs of component waves coincide. In other words, there is a variation of height superposed on the ordinary wave motion. It can also be shown that two simple wave trains moving in slightly different directions give a resultant pattern composed of 'short-crested' waves as distinct from the 'long-crested' waves of simple wave motions.

The speed of a wave group is not the same as that of the individual waves composing it. Each individual wave in its turn emerges from the dead water in the rear of the group, travels through the group and subsides in the dead water ahead of it. The speed of the wave group must therefore be less than the speed of an individual wave. Both theoretical considerations and experience show that the wave group travels at one half the speed of the individual waves.

The origin and travel of swell

Swell waves originate in the heavy seas created in a storm area. Short waves have an insufficient store of energy to enable them to travel long distances against the dissipating action of friction. Hence, in general, it follows that swell waves are long waves in comparison with the wind driven waves at the place of observation.

In calculating the distance travelled by swell, care must be taken to distinguish between the speed of the individual waves and the speed of the wave groups. If, for example, a ship reports the sudden onset of waves whose speed, calculated from the period, is 30 knots, then another ship in the line of advance of these waves will experience their onset at a time obtained by allowing a speed of 1/2 x 30 = 15 knots for the disturbance. As swell travels its height decreases. Investigations by the Institute of Oceanographic Sciences Deacon Laboratory show that if R is the distance from the point of generation in nautical miles then the amplitude of distance R is $\sqrt{(300/R)}$ of that at the point of generation by the wind. Thus, a swell would lose one-half of its height in travelling a distance of 1200 nautical miles. The long swells are the greatest travellers.

Waves in shallow water

All the previous remarks refer to waves in deep water. When a deep-water wave enters shallow waters it undergoes profound modification. Its speed is reduced, its direction of motion may be changed and, finally, its height increases until, on reaching a certain limiting depth, the wave breaks on the shore. Water may be regarded as shallow when the depth is less than half the length of the wave.

The decrease in speed when a wave approaches the shore accounts for the fact that the wave fronts become, in general, parallel to the shore prior to breaking. Figure 22 shows a wave, approaching the shore at an angle, being refracted until it becomes parallel to the shore.

The same reasoning may be applied to explain how waves are able to bend round headlands and to progress into sheltered bays.

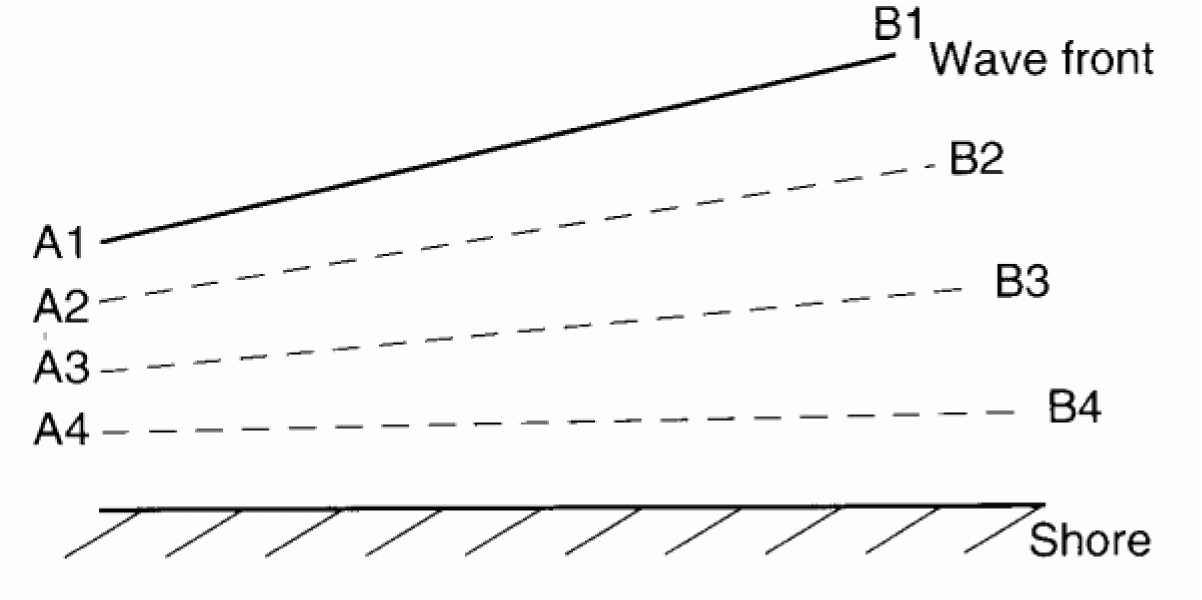

Figure 22. Refraction of a wave approaching the shore at an angle.

The inherent difficulties of observation
It has been mentioned earlier that the ideal observer is a wave-recorder which can register automatically the up and down motion of the sea surface at a fixed point. A typical record is shown in Figure 23. The record is, in general, complex and shows immediately all the difficulties inherent in eye observation. For example, are all the waves to be considered on an equal footing or are only the big waves to be counted?

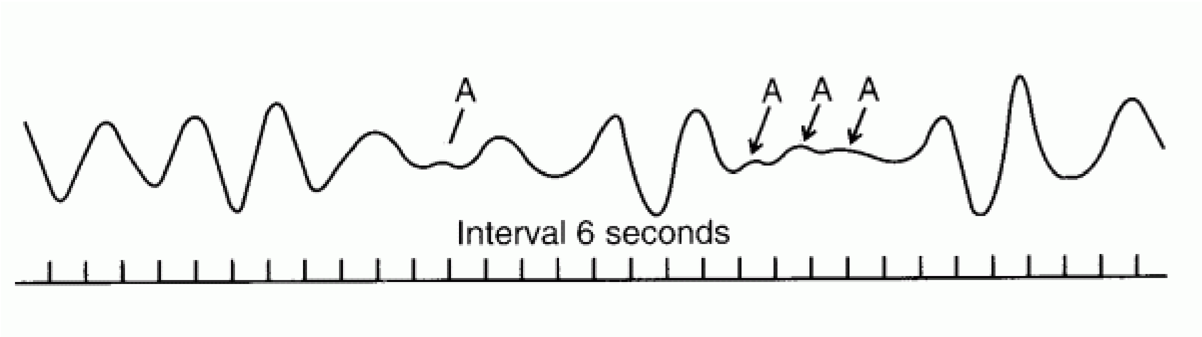

Figure 23. Wave form of the sea surface.

Since the wave characteristics vary so much, what average values shall be taken? It is obvious that if comparable results are to be obtained the observer must follow a definite procedure. The flat and badly formed waves ('A' in Figure 23) between the wave groups cannot be observed accurately by eye and different observers would undoubtedly get different results if an attempt were made to include them in the record. The method to be adopted, therefore, is to observe only the well-formed waves in the centre of the wave groups. The observation of waves entails the measurement or estimation of the following characteristics:

Direction Period Height.

Reliable average values of period and height can only be obtained by observing at least twenty waves. Of course, these cannot be consecutive; a few must be selected from each succeeding wave group until the required number has been obtained. Only measurements or quite good estimates are required. Rough guesses have little value and should not be recorded.

It will often be found that there are waves coming from more than one direction. For example, there may be a sea caused by the wind then blowing and a swell caused by a wind that has either passed over or is blowing in a distant area. Or there may be two swells (i.e. cross swells) caused by winds blowing from different directions in distant areas. In such cases the observer should distinguish between sea and swell, and report them separately, giving two groups for swell when appropriate.

The direction, height and period of the sea wave may be quite different from that of the swell wave. It will, however, often happen – particularly with winds of Beaufort force 8 and above – that the sea and swell waves are both coming from the same direction. In that case it is virtually impossible to differentiate between sea and swell and the best answer is to look upon the combined wave as being a sea wave and log it accordingly.

Observing waves from a moving ship

Care must be taken to ensure that the observations, especially those of period, are not influenced by the waves generated by the motion of the ship.

(a) *Direction from which the waves come*. This is easily obtained either by sighting directly across the wave front or by sighting along the crests of the waves and remembering that the required direction differs from this by 90 degrees.

(b) *Period*. For measurements of period a stopwatch is desirable. If this is not available an ordinary watch with a seconds hand may be used or, alternatively, a practised observer may count seconds. The observer selects a distinctive patch of foam or a small object floating on the water at some distance from the ship, and notes the time at which it is on the crest of each successive wave. The procedure is repeated for the larger waves of each successive group until at least twenty observations are available. The period is then taken as the average time for a complete oscillation from crest to crest. In a fast ship it will be found that the 'patch of foam' method will rarely last for more than one complete oscillation and that many waves have to be observed separately. With practice, suitable waves can easily be picked out and the timing from crest to crest becomes quite simple. When it is desired to use a suitably buoyant and biodegradable object, it should be thrown into the sea as far forward as possible. Another method available to the observer with a stopwatch is to observe two or more consecutive 'central' waves of a wave group while the watch is running continuously, then to stop the watch until the central waves of the next wave group appear, the watch being then restarted. This procedure is repeated until at least twenty complete oscillations have been observed. The period is then obtained by dividing the total time by the number of oscillations. It is important to note that the periods between times of crests passing a point on the ship are not the ones required.

(c) *Height.* Although wave-recorders are fitted to some research ships and marine automatic weather stations, there is at present no method of measuring the height of waves suitable for general use on merchant ships, but a practised observer can make useful estimates. The procedure to be adopted depends on the length of the waves relative to the length of the ship. If the length of the waves is short in comparison with the ship's length, i.e. if the ship spans two or more wave crests, the height should be estimated from the appearance of the waves at or on the side of the ship, at times when the pitching and rolling of the ship is least. For the best result the observer should take up a position as low down the ship as possible, preferably amidships where the effect of pitching is least, and on the side of the ship towards which the waves are coming.

This method fails when the length of the waves exceeds the length of the ship, for then the ship rises bodily with the passage of each wave crest. The observer should then take up a position in the ship so that his eye is just in line with the advancing wave crest and the horizon, when the ship is upright in the trough. The height of eye above the ship's water line is then the height of the wave. The nearer the observer is to an amidships position the less chance will there be of the measurement being vitiated by pitching. If the ship rolls heavily it is particularly important to make the observation at the moment when she is upright in the trough. Exaggeration of estimates of wave height is mostly due to errors caused by rolling. (See Figure 24. When the ship is rolling (b) the observer at 'O' has to take up a higher position to get a line on the horizon than when she is upright (a).)

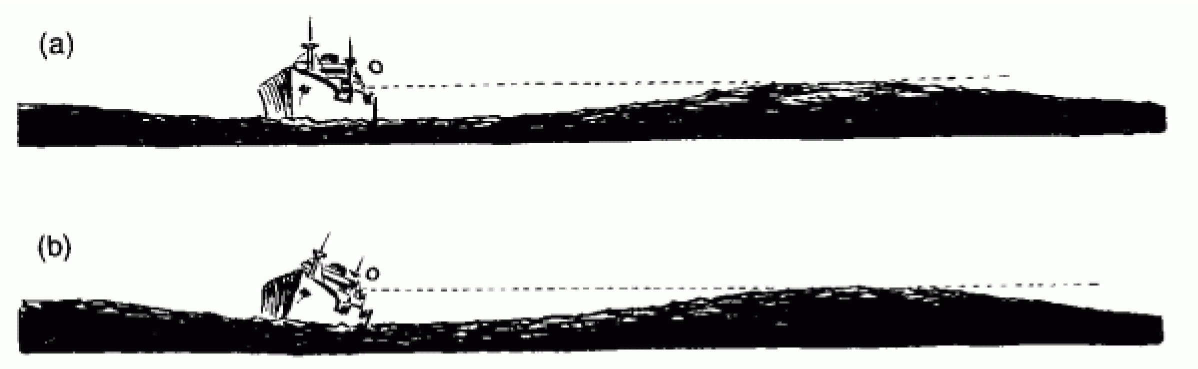

Figure 24. Estimation of wave height at sea.

The observation of height of waves is most difficult when the length of the waves exceeds the length of the ship and their height is small. The best estimate of height can be obtained by going as near the water as possible, but even then the observation can only be rough. In making height estimates an attempt should be made to fix a standard of height in terms of the height of a man or the height of a bulwark, forecastle or well-known dimension in the ship. There is generally a tendency to overestimate the height of long waves.

Estimating the height of a wave from a high bridge in a fast ship is a difficult job and much will depend on the skill and ingenuity of the observer; in many cases all one can hope for is a very rough estimate. All estimates of wave height should be made preferably with the ship on an even keel so that the observer's height of eye is consistent.

The inherent difficulties already mentioned, together with the practical difficulties of estimation, make it essential that the recorded height should be the average value of about twenty distinct observations. These observations should be made on the central waves of the more prominent wave groups.

Wave observations at night or in low visibility

Under these conditions the most that the observer can normally hope to record is direction and an estimate of height, or perhaps direction only, which would at least indicate the presence of waves. Such observations might be of considerable value in tropical waters in the hurricane season. It is only on very bright nights that the observations of period would be practicable.

Observing waves from weather ships

Wave-recorders, which can record the period and height of the waves, have been installed in most ocean weather ships. But even when no special instruments are carried, weather ships have the advantage of being able to manoeuvre so as to secure the best conditions for wave observation. The methods outlined in (b) may be used to better advantage than by ordinary merchant ships. For example, a floating object may be observed for a considerable time; it is not lost in the distance as occurs when the ship is moving.

In addition to these observations the height, length and period of waves can be determined from a stationary ship as follows:

(a) The estimation of wave height may be much assisted with the use of a dan buoy of known height.

(b) Length can be observed by streaming a buoy for such a distance astern that the crests of successive waves are simultaneously passing the buoy and the observer. This distance between the two is the wavelength.

(c) Period can be obtained by noting the time taken for the wave to travel the distance between the buoy and the observer.

By simple division the speed of the individual waves can be deduced

The importance of wave observations

The study of ocean waves has only recently been put on a scientific basis by the utilization of an automatic method of recording and the subsequent analysis of the record into component simple waves. The establishment of a network of specially equipped observing stations would probably add much to our present knowledge of the generation, transmission and decay of ocean waves. The new method of recording has made evident the limitations of former methods of observation, including the use of sea and swell scales, and has indicated the necessity of obtaining quantitative observations of wave characteristics.

Of practical importance is the fact that quantitative wave observations may be used for identifying the approximate position of a storm centre when suitable weather observations are lacking. The use of swell as an indication of the approach of a tropical storm is well known. The forecasting of swell on exposed coasts, such as those of Morocco and Portugal, is of considerable value for the protection of coastal shipping and port installations. The accuracy of these forecasts depends largely on an adequate supply of reliable ships' observations. Statistics of the period and height of waves would be of value to naval architects particularly in respect of stability, rolling and behaviour of the ship structure in a seaway.